



Eco-linkages and an optimal portfolio of resources: A step towards sustainable development

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Abstract

Industrial ecology has been promoted as a possible method to attain sustainability, by redesigning industry as an organisms-like community of companies, in order to increase material and energy efficiency. A common direction has been mainly focused on the end of the production process, while the concern of the portfolio of resources involved in the manufacturing process has been limited. This paper evaluates and presents the implications of developing eco-linkages, supported by a portfolio that has been designed using the DNP (De Novo Programming) method. The author argues that the new approach can deliver significant benefits to the main economic players in terms of profit, added value and environmental protection. In this context, sustainability becomes good business, while pollution means a loss of revenue and, possibly, also profit.

Keywords

Elimination of tradeoffs, industrial ecology, optimal portfolio, sustainability

JEL Classification: C61, L23, Q01

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1. Introduction

Starting with the definition of sustainable development, advanced by the World Conservation Union, as follows:

Improving the quality of human life while living within the carrying capacity of supporting ecosystems (IUCN, UNEP, WWF 1991), and continuing with the definition of waste used within the EU, as:

Any substance or object [...] which the holder discards or intends to or is required to discard (91/156/EEC), the vagueness of these formal statements becomes bitterly noticeable. Nevertheless, the existence of these definitions makes the presence of salient problems very obvious, as for instance, the depletion of raw materials, alarming pollution, global warming and, simultaneously, the lack of a straightforward solution.

Sustainability and the development of eco-societies have been addressed not only by governments, but also by scholars, activists groups and businesses. Researchers have developed different approaches, methods and tools. Among these, industrial ecology has evolved as a comprehensive framework due to its proposed rational use of natural resources and has gained increasing attention in recent decades. Its central tenet is built upon the overlap between biology and industry, see Brand and Bruijn (1999), Connelly and Koshland (2001) or Minulescu (2009). Within the field of industrial ecology, companies have been compared to living organisms, while connections between different economic players have been considered analogous to existing links among species within an ecosystem. In an ecosystem, living organisms consume other species' waste, and the flows of energy and materials are characterised by

circularity and efficiency. In a similar fashion, companies can re-organise into specific networks, where the flows of energy and materials are optimised and waste is considerably diminished or even eliminated. Current industrial systems exhibit high inefficiencies in their use of materials and energy, originating mainly from their open design. Industrial ecology promotes the development of sustainable industry, where enhanced use of raw materials and energy is obtained through the concatenation of companies from diverse sectors. Within the framework of industrial ecology, waste and pollution are no longer mere restrictions enforced through regulations, but are attributes of linear inefficient manufacturing processes (Porter and Linde, 1995), which alter a company's revenues. Consequently, management systems that integrate customers and suppliers enjoy remarkable earnings, concurrently delivering environmentally-friendly products and decreasing the rate of resource usage (Maslenninkova and Foley, 2000). In this manner, value creation is no longer pursued at the cost of the environment, or vice versa. However, focusing solely on companies' waste while disregarding the importance of resources before the production process, will partially solve the problem of resource depletion and pollution. Therefore, a new approach that combines the theory of industrial ecology and the concept of an optimal portfolio of resources is needed in order to prove the major implications of this new direction regarding profits or added value and the environment.

The objective of this paper is to show how a joint approach, which encompasses De Novo Programming, which is an optimisation method that allows the computation of an optimal portfolio of resources and industrial ecology, makes the protection of the environment possible while at the same time increasing a company's profits. In order to eliminate different shortcomings of surplus inventories, like raised costs (Lee et al., 1997), and additional waste generated by these suboptimal inventories (Sanderson, 1997, Aghazadeh, 2003), the author will choose to optimally design a portfolio of resources by applying De Novo Programming. Unnecessary production inputs are a burden for companies and the environment. Hence, a strategy for attaining sustainable development, a desired stage that implies the rational use of resources, would be incoherent without the integration of optimal inventories.

Moreover, using this algorithm, both profits and a proposed pollution index can be simultaneously maximised. As profits represent a part of the total added value (see Zeleny (2007, 2009) for further reading), it is therefore natural to see how value is influenced by the implementation of the principles of industrial ecology in conjunction with an optimal

portfolio. In this study, an example from the clothing industry will be used in order to present and discuss the results of applying this joint approach. The example will be tested under different conditions, starting with a given system and continuing with designing an optimal portfolio for the cases in which the manufacturer is or is not involved in eco-linkages respectively. The results of this study make evident the possibility of removing the trade-offs between profit and environmental protection and hence they can be considered as a remarkable step towards sustainable development. Additionally, the results can offer substantial support when both industrial ecosystem-planning activities are undertaken and actions regarding optimal portfolio are considered.

The paper is divided into six sections. The two sections following the introduction will offer brief descriptions of industrial ecology and the De Novo Programming algorithm respectively. Subsequently, a case study from the clothing industry will be presented, followed by a section in which the results will be exhibited and discussed. In the last section, the author will present a concise summary of the entire paper and draw conclusions based on the results obtained.

2. Industrial ecology

This paradigm was first seen in literature approximately four decades ago (Erkman, 1997) and has established itself as a business strategy (see also Harte et al., 2001) that allows companies to verge on sustainable development. Due to its short history, industrial ecology has been characterised by several inconsistencies, one of them being the presence of a plethora of definitions (Levine, 2003, Kibert et al., 2002, McManus and Gibbs, 2008). Nevertheless, researchers share a common vision regarding:

- *the resource perspective* – industrial ecology seeks to redesign the links among industrial systems from linear to circular, in order to optimise the use of energy and materials,
- *the system perspective* – through which industrial ecology advances an analogy between living organisms and companies, with respect to the level of physical exchanges of water, energy, information, and waste.

These two views are directed towards a common goal, which is to enhance added value by creating a new type of partnership based on the formal exchange of by-products, finally leading to a decrease in production costs. Similar networks of cooperation have been created under numerous labels. From these, the soundest descriptions are industrial ecosystems (Frosch and Gallopoulos, 1989), eco-industrial parks

(Côté and Cohen-Rosenthal, 1998) and industrial symbiosis (Chertow, 2000), all referring to how waste can be transformed into a valuable resource, inside or outside of a company's facilities. The first example of a functional industrial ecosystem, which was discovered in the city of Kalundborg in Denmark at the beginning of the 1990's, has inspired similar studies (Schwarz and Steininger (1997), Korhonen et al. (2002), Bossilkov and Berkel (2004), Geng et al. (2007) and Ashton (2008), which have made it possible to identify eco-linkages. The enthusiasm shown by these spontaneous eco-industrial parks has triggered numerous efforts to replicate this novel type of network. Accordingly, various actions have been undertaken, mainly directed towards re-introducing waste in terms of materials and energy into the manufacturing process – Korhonen (2001), Côté and Hall (1995), Robèrt (2000), Mirata and Emtairah (2005) and Lowe and Evans (1995), while the idea of an optimal portfolio of resources has not been explicitly addressed (Lowe, 1997). It is thus striking to observe that although industrial ecology seeks to promote sustainable development, its focus is short-sighted, disregarding the fact that unnecessary inventories "encourage" resource depletion and the degradation of our environment. Moreover, the economic implications of sustainability and industrial ecology must be addressed openly, as companies' activities are deployed based on monetary considerations. Without stressing the direct economic benefits that a sustainable industry brings, as opposed to the old belied concepts to which revenues and sustainability are exclusive concepts, (Xepapadeas and Zeeuw (1999), Alexander et al. (2000)), the risk is that the transition towards this desired stage will be much slower than one would wish.

3. The De Novo Programming method

De Novo Programming (DNP) is an optimisation method based on flexible constraints and which allows the minimisation and/or maximisation of multiple objective functions (see Zeleny 2005a, 2005b, 2009 for further reading). Although a case from the clothing

industry will be used as a model, this method can be used for numerous industries and not just restricted to the aforementioned situation. DNP differs from traditional algorithms that deal with optimality, as the latter require a priori specification of different problem specifications and allow a single-objective optimisation.

4. Case study

A case study, in which various situations involving a clothing manufacturer was conducted in order to evaluate the consequences of portfolio and waste on profits and a pollution index. Additionally, it is interesting to note the changes induced to added value in each situation. These cases are summarised in Table 1.

Table 1 Situations examined in the case study

Case	Eco-linkages	DNP
0	–	–
1	x	–
2	x	x
3	–	x

x is the presence of waste re-utilisation or an optimal portfolio determined with DNP, while – states the contrary.

Input data for a production process has been adapted from Zeleny (2005a) and is presented in Table 2, while the allocated budget is limited to \$2600.

The price of X is \$754 and of Y is \$678, while customers would pay a maximum price of \$800 and \$700, respectively. Added value per unit is computed according to Zeleny (2007) as follows:

$$AV_x = 800 - 354 = \$446$$

$$AV_y = 700 - 378 = \$322,$$

where \$354 represents the production costs for X, and \$378 represents the production costs for Y. Accordingly, profits per unit are:

$$P_x = 754 - 354 = \$400$$

$$P_y = 678 - 378 = \$300.$$

Table 2 Data for the production process

Unit price (\$)	Resource	Technological coefficients		Portfolio
		X = 1	Y = 1	
30	Nylon	4	0	20
40	Velvet	2	6	24
9.5	Silver thread	12	4	60
20	Silk	0	3	10.5
10	Golden thread	4	4	26

X & Y represent two distinct goods produced by the manufacturer

Source: Zeleny (2005a)

During the manufacturing process, an important quantity of waste is obtained. The scraps resulting from trimming operations for each released product are available in Table 3.

Table 3 Waste resulting from trimming operations

Resource	Technological coefficients	
	$X = 1$	$Y = 1$
Nylon	0.2	0
Velvet	0.15	0.2
Silver thread	0.1	0.1
Silk	0	0.3
Golden thread	0.1	0.15

When the company becomes aware of the quantity of waste that they produce, they consider a solution that would reduce their total costs. An answer would be to sell the entire waste to a local carpet manufacturer at a price of \$40. This additional revenue can be seen as a decrease in the initial price of raw material by \$8. The new data is summarised in Table 4.

Waste re-utilisation leads to different values of added value per unit as follows:

$$AV_x = 800 - 178 = \$622$$

$$AV_y = 700 - 242 = \$458,$$

while profits adjust accordingly as follows:

$$P_x = 754 - 178 = \$576$$

$$P_y = 678 - 242 = \$436.$$

Selected values of the pollution index are 5 points for X and 12 points for Y , on a scale from 1 to 20 where 20 indicates a pollution-free manufacturing process.

5. Results and discussion

Table 5 presents the differences that occur between the four cases for the added value per product, objectives to be optimised (profits and pollution

index), their final values, portfolio of resources and budget.

It can be seen that the profits reached higher values when eco-linkages were developed (Case 1 and Case 2), while the pollution index scored high when an optimal portfolio was designed (Case 2 and Case 3). Another significant outcome of an optimally designed portfolio is the elimination of surplus inventories (Case 2 and Case 3), a statement that is no longer valid when suboptimal inventories were used (Case 0 and Case 1).

The two cases where waste was reused (Case 1 and Case 2) exhibit a remarkable increase in profits. Particularly in Case 2, where a combination between eco-linkages and an optimal portfolio of resources shows itself due to the highest values obtained for both objectives for the same mix of products. The combination does not force the company to alter their initial budget of \$2600. Moreover, the producer no longer needs to trade profits over environmental protection, or vice versa. Additionally, added value per product for both X and Y scores highest for both Case 1 and Case 2 when the re-utilisation of waste is considered.

Another interesting situation can be seen in Case 3, in which the portfolio was optimally designed. Although the two objectives are fulfilled by the same mix of products ($X = 2.56$, $Y = 4.47$), the values of profits and the pollution index are lower than in Case 2, where the portfolio was again designed using DNP but accompanied by waste reutilisation.

Furthermore, it is interesting to note the differences that occurred between Case 0 and Case 3. It can be seen that the profits are higher and the pollution index is lower in Case 0 than in Case 3 respectively. A valid explanation for this situation is the separate treatment of objectives by linear programming (Case 0) and the joint treatment of the two equally important functions – profits and the pollution index by DNP (Case 3).

Table 4 New data for the production process when the clothing producer is involved in eco-linkages

Unit price (\$)	Resource	Technological coefficients		Portfolio
		$X = 1$	$Y = 1$	
22	Nylon	4	0	20
32	Velvet	2	6	24
1.5	Silver thread	12	4	60
12	Silk	0	3	10.5
2	Golden thread	4	4	26

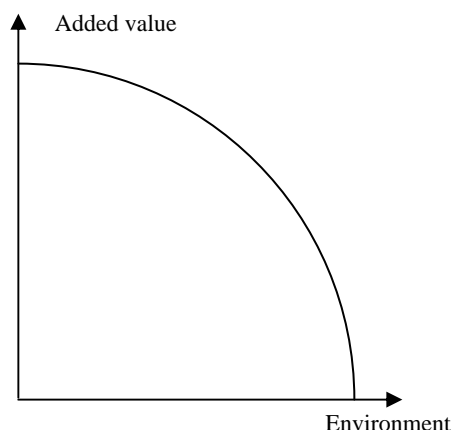


Figure 1a Trade-off between added value and environment
Source: Minulescu and Birtu (2009)

Nevertheless a comparison between the allocated budgets in Case 0 and Case 3 indicates the presence of a surplus of money in Case 3, which offsets the difference between the profits.

Having presented the above results, it is pertinent to infer that the joint approach offers extraordinary achievements. Industrial ecology principles in conjunction with an optimal portfolio of resources greatly enhance a company's performance in terms of profits and pollution reduction. These two functions

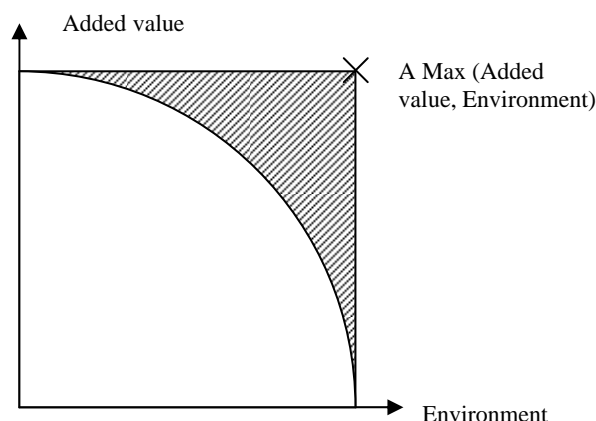


Figure 1b Eliminating the trade-off

are no longer exclusive objectives. In this fashion, the trade-off between profit and environmental protection, or between added value and environmental protection (Figure 1a) is eliminated (Figure 1b).

This study did not consider the situation when the clothing company first decides to utilise the waste within their own manufacturing processes and then sell the final waste when certain technological co-efficiencies are no longer met. Further research is needed in order to fully explore the potential of

Table 5 Results of the modelled cases

Case	Added value/product	Objectives to be optimised	Final values of optimised objectives	Portfolio	Budget
0	$AV_X = \$446$ $AV_Y = \$332$	$f_1 = 400x + 300y$ $f_2 = 5x + 12y$	$f_1 = \$2375$ ($X = 4.25, Y = 2.25$) $f_2 = 51.75$ ($X = 3.75, Y = 2.75$)	20 24 60 10.5 26	\$2600
1	$AV_X = \$662$ $AV_Y = \$458$	$f_1 = 576x + 436y$ $f_2 = 5x + 12y$	$f_1 = \$3429$ ($X = 4.25, Y = 2.25$) $f_2 = 51.75$ ($X = 3.75, Y = 2.75$)	20 24 60 10.5 26	\$1476
2	$AV_X = \$662$ $AV_Y = \$458$	$f_1 = 576x + 436y$ $f_2 = 5x + 12y$	$f_1 = \$6562.51$ $f_2 = 100.56$ ($X = 7.37, Y = 5.3$)	29.5 46.59 109.74 15.91 50.73	\$2596.87
3	$AV_X = \$446$ $AV_Y = \$332$	$f_1 = 400x + 300y$ $f_2 = 5x + 12y$	$f_1 = \$2367.87$ $f_2 = 66.52$ ($X = 2.56, Y = 4.47$)	10.25 31.98 48.65 13.42 28.15	\$2563.15

recycling within and outside of a facility, accompanied by an optimal portfolio. Additionally, the study did not consider the possible costs that might arise from transporting waste, incentives or barriers to recycling, or social aspects regarding cooperation between companies. Nonetheless, the current study represents an important starting point towards delving into the issues of profits, added value and sustainability.

6. Conclusion

This study demonstrated how the DNP algorithm can be used in conjunction with the application of the principles of industrial ecology as an efficient tool to remove the trade-off between a company's revenues and the environment. DNP has been designed as a method that allows the optimisation of multiple objectives, thus eliminating different trade-offs (Zeleny – 2005a, 2005b), while the latter framework has evolved as a business strategy that is meant to reduce or eliminate inefficiencies by discovering new opportunities for by-products, both inside and outside of a company's facilities.

The results put forward in this paper indicate the noteworthy benefits that this new approach can bring to businesses. A major implication of the proposed approach is the removal of the trade-off between profits or added value and the environment. In this manner, companies can develop sustainable activities as a means to secure and augment their revenues. It can be concluded that the protection of the environment can be transformed from mere activities undertaken by CSR departments into good business. The four cases presented in this paper were analysed according to their particular conditions, which included the presence or absence of eco-linkages and/or an optimal portfolio, along with the modifications induced by these conditions to the two objective functions – profits and pollution index respectively. Furthermore, the modifications of the added value for each case were investigated.

The study did not explore the situation when waste is re-introduced into the initial production process and ultimately sold to a second party, nor did it consider issues of transportation costs, regulations or inter-organisational relationships. However, it can be inferred that it is possible to present the benefits brought about by sustainable development built on eco-linkages and optimal portfolios. Companies who choose to consider pollution and waste as characteristics of inefficient production processes will be the first ones to promote and reach sustainability.

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